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14. ABSTRACT
The procedures in this TOP describe how to evaluate the cooling characteristics of engine, power train, and auxiliary components of wheeled and tracked vehicles when subjected to full- and part-throttle vehicle operations, repeated steering maneuvers, and exposure to extreme environments. The necessity for engine and power train cooling arises from inherent mechanical and thermal limitations of vehicle components and their lubricants, heat buildup from sources such as ambient temperature and solar radiation, and increased operational demands resulting from overloads or increasing loads. To prevent damaging effects to power-producing and power-transmitting components, care must be exercised by the user to see that operating temperatures are maintained within specified limits under all conditions.

15. SUBJECT TERMS

Air-Cooled Engines	Liquid-Cooled Engines	Steering Effect	
Auxiliary Engine	Mechanical Transmissions	Wide-Open Throttle	Full Throttle
Cooling Tests	Operating Gears	Fluid Transmissions	Part Throttle

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U.S. ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 2-2-607 — 27 September 2006
DTIC AD No.

COOLING SYSTEMS (AUTOMOTIVE)

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1. SCOPE.

a. The procedures in this Test Operations Procedure (TOP) describe how to evaluate the cooling characteristics of engine, power train, and auxiliary components when subjected to full- and part-throttle vehicle operations, repeated steering maneuvers, and exposure to extreme environments. Reduced data from the test are intended to support an analysis of the performance of the cooling system.

*This TOP supersedes TOP 2-2-607 (DTIC No.: A093823), 13 January 1981, with change 1.

b. The necessity for engine and power train cooling arises from inherent mechanical and thermal limitations of vehicle components and their lubricants, heat buildup from sources such as ambient temperature and solar radiation, and increased operational demands resulting from overloads or increasing loads. The testing of these cooling systems under different stresses reveals the critical operational loading points at which cooling performance is degraded or failed.

c. Testers, evaluators, system developers, and other primary stakeholders in the test (and the system under test) are the intended audience for this document and the procedures herein.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Off road courses	To provide an operational evaluation of the cooling system based on the vehicle's mission profile.
Level paved test courses	To provide continued operation at sustained speeds.
Mountain road load course	To provide an average grade of 6% or greater and of sufficient continuous length to allow the vehicle to stabilize at a minimum speed for sustained operation.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Mobile field dynamometer as required, (applicable resistive load)	
Temperature	Thermocouple, K – TYPE Standard: ±2ºC (3.6ºF) or 0.75%
	Thermocouple, J-TYPE Standard: ±2ºC (3.6ºF) or 0.75%
	Thermocouple, T-TYPE Standard: ±1.0°C (1.8ºF) or 0.75%

Devices for Measuring	Permissible Measurement Uncertainty
Engine speed and fan speed	±10 rpm
Pressure	±1% of full scale; Absolute Transducers: 0.11% of full scale Differential Transducers: 0.75% of full scale
Vehicle speed	±0.2 km/hr (0.1 mi/hr)
Ambient air temperature	±2ºC (3.6ºF)
Relative humidity	±3% (0 to 90%) and ±4% (90 to 100%)
Barometric pressure	±1.0-mm Hg (±1.4 hPa/mb)
Wind speed	±2 kts, 3 km/h, 1 m/s or ± 5%, (whichever is higher)
Wind direction	±7 degrees
Solar radiation	±5% of full scale
Air speed indicators	±1%
Drawbar Force	±1%

2.3 Test Controls.

Measurement Uncertainty is described by American Society for Testing and Materials (ASTM) in the Form and Style for ASTM Standards[1] as "an estimate of the magnitude of systematic and random measurement errors that may be reported along with the measurement result." It provides a dispersion range for the measurement and increases confidence in the validity of the measurement. Random errors are defined as statistical fluctuations that occur in either direction of the true value. Because random errors fluctuate in both directions of the true value when summed, they tend toward zero and are eliminated through repeated measurements. Systematic errors (or bias) are reproducible across experiments and tend to be in one direction. Systematic errors are sources of uncertainty and should be identified and, if possible, mitigated or evaluated.

3. REQUIRED TEST CONDITIONS.

3.1 Vehicle Identification.

Determine the following:

a. Vehicle model, serial number, and manufacturer.

b. Engine model, serial number, manufacturer, and maximum operating temperatures (engine oil and coolant or cylinder head).

c. Transmission model, serial number, manufacturer, and maximum operating temperature.

d. Maximum operating temperatures of gearboxes.

e. Gear ratios of all gearboxes.

f. Sprocket rolling distance or loaded tire diameter.

g. Vehicle cooling requirements per vehicle specifications, materiel need, etc.

h. Tire pressure (wheeled).

i. Track tension (tracked).

j. Vehicle test weight, overall and axle weights.

3.2 Test Preparation, Planning, and Considerations.

a. Prepare test vehicle in accordance with (IAW) applicable methods addressed in TOP 2-2-505[2] prior to tests.

b. Perform maintenance and servicing to ensure that the vehicle is in condition for optimum performance. Give particular attention to:

(1) Cooling system.

(2) Cooling fan drive mechanisms (e.g., fan belt tension, drive shafts, etc).

(3) Proper lubricants and lubricant levels. Samples of coolants and lubricants should be taken prior to and after testing to evaluate contamination, additive breakdown, and wear metals.

(4) Proper operation of pressure caps, heat riser valves, and any other components that affect engine and power train component temperature directly.

(5) Shrouds, seals, and air dams are installed and functional, as necessary.

c. Block open all thermostats to permit maximum coolant or oil flow, and alter thermostatically-controlled fans to obtain positive drive, as required. Measure the distance that the thermostat is blocked open to and record a photograph.

d. Ensure that the vehicle contains the proper fuel per engine specifications, and the appropriate liquid coolant mixture when applicable. Follow specific guidance in Technical Manuals (TMs); if none, use a 50% water/50% ethylene-glycol mixture, except when arctic antifreeze is required.

e. Load non-combat test vehicles to gross vehicle weight (GVW) and combat vehicles to gross combat weight (GCW).

f. Vehicle Configuration – Determine settings for variable vehicle sub-systems required for specified test conditions (i.e. Central Tire Inflation System (CTIS), transfer case, wheel drive setting (i.e. 2x4, 4x4, 4x6, etc), auxiliary systems such as air conditioning, communications, other mission equipment, etc).

g. Tires – Ensure the correct model, type, and size of tire is mounted on the test vehicle and the tires are in good condition. Record the tire pressure prior to conducting the test. If CTIS is used, record the selected mode, programmed nominal pressure for that mode, and the actual tire pressures. Calculate tire diameter and rolling circumference for all settings used.

h. Parasitic Loads – For hybrid electric or other atypical drive trains, determine appropriate parasitic electrical loads provided by the generator or alternator by measuring current and voltage as required. Parasitic hydraulic loads from power steering pumps and power take-offs (PTO's) should be measured using appropriate pressure and flow transducers as required.

i. Electronic Transmission – If the test vehicle is equipped with an electronically-controlled transmission, verify prior to test that the transmission will stay in the selected gear while under load. Some electronically-controlled transmissions may not remain in the selected gear. This behavior can be overridden in some cases (check with the material developer).

j. Electronic Engine Control – Engines equipped with an electronic engine control module may operate in a degraded state when subjected to high temperature stresses. This behavior can be overridden in some cases (check with the manufacturer).

k. Exotic Drive Trains – Electric, hybrid-electric, or hybrid-hydraulic drive trains may require variations from test procedures detailed within this TOP.

l. Cooling systems – Determine the following cooling system characteristics:

(1) Cooling fan drive actuation (electronic or mechanical), speed control (thermistor, viscous clutch, or electronic), and setting (locked vs normal).

(2) Location, quantity, and type of auxiliary fans if applicable.

(3) Heat exchanger description:

(a) Cooling medium (air, coolant, oil).

(b) Basic dimensions (length, width, thickness).

(c) Cooling flow patterns (i.e. counterflow, axial, or crossflow).

(d) Fin density.

(e) Number of rows of cooling tubes/fins.

(f) General condition. Ensure all heat exchangers are clean.

m. Tracked Vehicles – Preparations and considerations as described previously will be generally applicable for tracked vehicles. However, tracked vehicles will generally require a slightly different array of cooling tests (e.g., temperature rise from steering, in addition to full throttle testing).

n. Due to the wide variety of possible configurations, coordination with the material developer, with respect to specific test configuration, may be required.

o. These tests are limited to engines and power trains contained in wheeled or tracked vehicles. Tests will not be conducted in snow, rain, high wind, or when vehicle power is known to be below normal for reasons other than atmospheric conditions. The four conditions, which have the most impact on the stabilization of temperatures, are:

(1) Wind direction.

(2) Wind speed.

(3) Changing/rising ambient temperatures, which cause a related change in vehicle temperatures.

(4) Fluctuation in drive line loading caused by test course gradient and dynamometer load/speed control.

p. Wind effects may vary appreciably with vehicle design because of influences on air flow and recirculation and corresponding effects on cooling effectiveness. For example, wind blowing parallel to the course may result in the inability to stabilize temperatures, especially for vehicles with front-mounted radiators.

q. Cooling tests are generally not conducted at ambient temperatures below 21°C (70°F) due to extrapolation error (extrapolation of results is based on a 1-degree rise in component temperature per 1-degree rise in ambient temperature).

3.3 Vehicle Instrumentation.

The minimum instrumentation requirements should be primarily driven by the needs of the test and what specification requirements are being evaluated. Additional instrumentation may be installed to provide supplemental information that may be useful in further documenting and diagnosing any discrepancies. Instrumentation includes the following:

a. Thermocouples should be installed to measure critical engine, power train, and auxiliary component temperature as required for each specific vehicle to adequately determine and evaluate cooling characteristics. As a minimum, all critical temperatures per the vehicle specification are required. Where applicable, thermocouples should be installed to measure temperature of:

(1) Engine oil sump, inlet and outlet of engine oil cooler.

(2) Gearbox oil sumps to include wheel ends, inlet and outlet of any gearbox cooler.

(3) Transmission fluid sump, inlet and outlet of transmission cooler.

(4) Coolant to and from radiator.

(5) Fuel in tank, to and from engine.

(6) Power steering reservoir, inlet and outlet of fluid cooler.

(7) Hydraulic reservoirs, inlet and outlet of fluid cooler.

(8) Sufficient temperature measurements should be taken across the heat exchanger surface to document potential hot spots or stagnation areas.

(9) Ambient temperature. Measured at 1.0 meter (3.3 ft) in front of test vehicle grille on the approximate center line of grille opening (ref Society of Automotive Engineers (SAE) J1393[3]). For test vehicles without a grille, ambient temperature should be measured at 1.0 meter (3.3 ft) in front of test vehicle along vehicle center line at 2.0 meters (6.6 ft) high.

(10) Ram air to heat exchanger.

(11) Others such as those needed for Human Factors/ MANPRINT evaluations, as appropriate.

b. Transducers or gauges should be installed to measure pressures for:

(1) Engine oil.

(2) Transmission, including main, torque converter lockup, and clutch application pressures.

(3) Fuel system before and after filters; it is generally not recommended to measure fuel pressures of high-pressure lines due to possible complications.

(4) Coolant system.

(5) Combustion air (air cleaner restriction, turbo boost, manifold vacuum, or air box pressure, as required).

(6) Other components, as appropriate.

c. Tachometers, pulse counters, or gauges should be installed to measure speed of:

(1) Engine.

(2) Cooling fan(s).

(3) Wheel or sprocket.

(4) Test vehicle.

d. Drawbar force measurements.

e. Automotive databus. Several of the aforementioned data can be captured via the vehicle's databus (if present). Calibration of databus parameters should be conducted prior to accepting data for use in an evaluation. Other considerations should include sample rate(s) from the bus and whether the broadcasted parameter is directly measured, calculated by manufacturer algorithm, or provided from a look-up table.

4. TEST PROCEDURES.

All critical component temperatures should be monitored realtime during all testing to identify problem areas and to watch for stabilization. Temperature stabilization of the critical components is defined as when the temperature is not rising and there is no more than a 2.8ºC (5ºF) variation in fluid temperature in one direction of travel, or no more than a 5.6ºC (10ºF) variation in fluid temperature in both directions of travel over a minimum 10-minute period. Stabilization criteria are determined from U.S. Army Materiel Command Pamphlet (AMCP) 706-361[4].

Operational fluid temperature limits for typical military specification fluids is provided as a reference in Appendix A. Verify the fluid type and limitations are applicable to the test vehicle before use.

4.1 Tractive Effort/Resistance-to-Motion.

The resistance-to-motion of the test vehicle must be determined prior to the cooling tests described in Paragraph 5.3. TOP 2-2-605[5] is the primary governing document for this test. The test item's resistance-to-motion is a speed-dependent load representing the power losses of the test item drive train, tire rolling resistance, grade, and aerodynamic drag and is used to calculate the Tractive Effort (TE) used in testing. TE is the total force available to move the vehicle. Drawbar pull (DBP) is the reserve load available for acceleration, towing trailers or other large payloads, or overcoming mobility challenges such as grades or other obstacles. Vehicle specifications are commonly presented as a ratio of TE to vehicle weight. The following equation is used to derive the TE and can be manipulated to calculate the dynamometer drawbar loading required for retardation to achieve a given TE.

Tractive Effort (N (lbf)) = Resistance-to-Motion (N (lbf)) + Drawbar Pull (N (lbf))

NOTES 1. Due to the low vehicle speeds required to obtain the high TE during typical full load cooling tests, the resistance to vehicle motion due to air resistance is negligible and the vehicle rolling resistance can be utilized in place of resistance-to-motion.

2. For the purposes of cooling tests on level terrain, the resistance-to-motion due to grade is also considered to be negligible.

4.2 Drawbar Pull.

The drawbar pull test provides data that are useful in the execution of wide-open throttle tests described in Paragraph 4.3. Guidance is provided in TOP 2-2-604[6].

4.3 Full Load Cooling Tests (Wide Open Throttle).

4.3.1 General Method.

a. The radiator thermostat should be blocked open, refer to Paragraph 3.2.c.

b. Other thermostats should be blocked open to allow maximum flow and cooler line bypasses should be closed to any flow, if appropriate.

c. Thermostatically-controlled fans should be locked in a maximum speed condition, if possible.

d. Use a mobile field dynamometer and its related equipment to apply a load condition to the vehicle under test. The load on the test vehicle is controlled by the field dynamometer to maintain the required test conditions.

e. Operate the vehicle at full throttle, in the desired gear, in all wheel drive (if a wheeled vehicle), and at the same constant speed for both directions of travel over a straight, paved road within 1% of level until the temperatures of the critical components are stabilized or exceed their temperature limits.

f. If temperature stabilization does not occur, then collected data can be utilized to evaluate trends in temperature rise versus time.

g. The temperature of inadequately cooled components may not stabilize, and therefore, may exceed critical temperature limits. If a critical temperature limit is exceeded, the test should be interrupted and the load reduced to allow the component to cool down and the deficiency documented.

h. Testing may be performed as required under the following vehicle conditions:

(1) Specified TE.

(2) Maximum torque.

(3) Maximum engine speed.

(4) Maximum rated engine power.

(5) Maximum converter speed.

(6) Reduced load or other condition if cooling requirements were not met at the required test condition(s).

(7) Other test conditions (e.g., air conditioners or other accessory systems activated) as required.

i. When a test condition such as TE/GVW ratio is specified, it is conducted in the lowest gear range that provides the condition unless otherwise specified.

4.3.2 Vehicles with Clutch Operated/Manual Shifted Mechanical Transmissions.

a. Determine which gear ranges provide sufficient torque to start the vehicle moving with some load applied, as mechanical transmissions cannot be shifted under full load (the vehicle must be stopped to shift).

b. Place the transmission in pre-determined gear range. Allow the vehicle to move by slipping the clutch at part throttle with an assist from the dynamometer vehicle and when at speed, gradually transition to full throttle as the dynamometer vehicle applies more load.

c. Operate the vehicle at the specified test condition until all critical component temperatures stabilize or exceed their critical temperature limits. Record all data while testing to reach stabilized conditions.

4.3.3 Vehicles with Automatic–Shift Transmissions.

a. Unlike the clutch operated/manually shifted transmission vehicles, these vehicles can shift gear ranges without stopping. When connected to a mobile field dynamometer, whether you should up-shift or down-shift at full load conditions will depend on the capabilities of the mobile dynamometer equipment relative to the item under test. It may be desirable to determine the shift points of the vehicle under full throttle acceleration or drawbar pull test prior to initiating full load cooling tests.

b. Automatic transmissions may be mechanically- or electronically-controlled and will likely automatically up-shift at higher road speeds than it will down-shift between the same two gear ranges.

c. A discussion with the Material Developer and/or applicable manufacturer is generally needed to determine:

(1) Torque converter operation in each gear range (converter, lockup, or both)

(2) The gear ranges the transmission will automatically shift between in each driver selectable range and whether there is a way to ensure the transmission will not automatically up-shift during the test (needed to test at rated horsepower or maximum engine speeds).

(3) Which transmission clutches are applied for each gear range and where the clutch pressures can be measured by instrumentation to determine which gear range is in use during testing. Alternatively, this information may be available via one of the vehicle electronic busses.

d. When test conditions such as a converter speed ratio (ratio of the torque converter output shaft speed to the input shaft speed) or a TE/GVW ratio is specified as a test condition, it conducted in the lowest gear range unless otherwise specified.

e. Place the transmission in the pre-determined gear range to conduct the appropriate full load cooling test. Start moving the vehicle at part throttle while applying load with the dynamometer vehicle. After the vehicle shifts to the desired gear range, transition to full throttle while increasing the load from the dynamometer to obtain the test speed. Record all data while testing to reach stabilized conditions.

f. Operate the vehicle at specified test condition until all critical component temperatures stabilize or exceed their critical temperature limits.

g. As electronic controls and engine/drive train mapping become more common, the vehicle drive train may not maintain test configuration (engine speed/power output/gear range) at high component temperatures in order to stabilize. The vehicle may automatically reduce power output as component temperatures approach critical limits. Potential reprogramming of the system may be possible to enable the vehicle to maintain the required conditions for full load testing. If the drawbar load starts to decline at high temperatures and cannot be re-attained with a decrease in road speed, engine power mapping, a non-fuel temperature compensated injection system, or other factors may be the cause and require discussion.

h. Hybrid electric vehicles will require battery performance measurements. Conditions for full load testing should be selected to identify charge depleting and charge sustaining conditions. Degraded modes should be identified. Peak and sustained performance should be measured.

4.4 Road-load Cooling Tests (Without a Field Dynamometer)

a. General Considerations.

(1) Road-load cooling tests are conducted at road speeds from the upper range of full load cooling tests to near the maximum speed of the vehicle.

(2) Tests should be conducted with and without a towed load as appropriate to the item under test (at GVW and GCW).

(3) Road-load cooling tests can be conducted at part throttle conditions and at (or near) full throttle conditions.

(4) A towing dynamometer can be used to simulate small grades depending on the capabilities of the dynamometer.

b. Part Throttle Tests. Part throttle cooling tests are conducted on a test course with no sustained grades with a fully functional cooling system and do not require extended periods of operation at full throttle. This test is used to evaluate the normal range of operating temperatures for critical components and Human Factors Engineering (HFE) items (such as crew surface temperatures).

(1) Operate the test vehicle over the test courses or parts thereof at a sustained operating speed until the temperatures of the critical components follow repeatable trends through each traverse of the course.

(2) Repeat at additional speeds or drive train configurations as necessary.

c. Full Throttle Tests.

(1) Maximum Safe Speed.

(a) Full-throttle or near full-throttle road-load cooling tests can be conducted on roads that are nearly level or involve minor rolling terrain where it is safe to operate the vehicle in the highest transmission gear range at maximum vehicle/engine speeds limited by power or safety considerations. If the vehicle can exceed indicated maximum speeds (provided by data plate or in the manual), then discuss with the test sponsor/evaluator what test conditions to utilize. If the vehicle is not so equipped, provide the operator with the capability to monitor the engine speed so not to exceed the rated maximum engine speed. If these tests are conducted on public roads, do not exceed posted speed limits and obey all traffic signals.

(b) This test is used to evaluate the repeatable range of operating temperatures of critical components and HFE items, and whether gearboxes (such as differentials) will overheat during sustained operation. When the critical components exhibit repeatable temperature ranges with each succeeding traverse of the course, then the average temperature of the critical components may be extrapolated to the vehicles required ambient operating temperature. If these temperatures are not repeatable but continue to rise, then the maximum temperature should be identified as such and then extrapolated.

(2) Mountain Road-load.

(a) Mountain road-load cooling tests can be conducted at full-throttle conditions on roads of continuous grade. Determine the transmission shift points on level roads prior to this test.

(b) Most military vehicles utilize automatic transmissions that will shift between gear ranges as needed. Tests are conducted at full throttle conditions in various gear ranges (low to high gears) going up the grade. The initial test of a vehicle when ascending a grade should be in a higher gear range than necessary to allow the transmission freedom to shift in order to evaluate transmission behavior. If downshifts do not occur normally, overheating may rapidly ensue. If the vehicle is not so equipped, provide the operator with the capability to monitor engine speed so not to exceed the rated maximum engine speed. If possible, down grade portions should be avoided.

(c) When descending grades, tests are conducted at part throttle conditions, with the vehicle coasting in gear at speeds potentially up to maximum speed with various throttle positions, and with transmissions manually downshifted (most vehicles have transmission

downshift inhibitors to prevent downshifting at road speeds which will cause an engine overspeed condition). Transmissions are often used for braking control on down grades and transmission fluid temperatures may be higher when coasting or when downshifting than during full-throttle conditions ascending a grade. Determining the maximum speed in each gear on level ground before conducting the downshift tests will provide an added measure of safety. Do not exceed maximum rate engine speed when descending a grade in the lower transmission gears.

(d) Auxiliary braking devices such as engine brakes, transmission retarders, and exhaust brakes may affect the component temperatures and should be considered in test planning.

(e) Mountain road-load cooling tests require ambient temperatures to be acquired at multiple known elevations from the bottom of the grade to the top of the grade, or the recording of Global Positioning System (GPS) elevations and ambient mast temperatures to perform data extrapolation to the vehicles required operating temperature. The temperature versus elevation data are used to determine a linear regression equation with the ambient temperature being a function of the elevation. The zero elevation temperature is used as the estimated ambient test temperature. This is a simplification of complex variables that change the ambient temperatures during the mountain grade test periods and account for the vehicle required operating temperature (normally based on Army Regulation (AR) 70-38[a]) being understood to be at or near sea level conditions. This enables an estimate of a near sea level ambient temperature based on local conditions when the minimum elevation may actually significantly be above sea level.

(f) The mountain road-load cooling tests do not consider the temperature ranges or average temperatures of components during the test since the ambient air temperatures are constantly changing with increases or decreases in elevation. Instead, this test evaluates the maximum component temperatures generated during a single test while ascending or descending a grade. The data are presented as maximum temperatures and the critical components maximum temperatures are extrapolated to the specified temperature based upon the estimated ambient temperature discussed in the preceding paragraph. The extrapolated maximum temperatures are then compared to the temperature limits.

(g) The minimum temperature for testing should not be less then 21ºC (70ºF) at the highest altitude obtained. The length of the grade should be of sufficient length to provide temperature stabilization on the vehicle using current stabilization definitions. Two courses have been historically used for this testing: Death Valley National Monument, California and Interstate 15 from Baker, California to Jean, Nevada. Death Valley National Monument has grades ranging from 3 to 11% (7% average), with routes ranging from 8 to 33 miles in length that go from 200 feet below sea level up to 6,000 feet. Interstate 15 from Baker, California to Jean, Nevada has an average grade of 6% on the eastbound climb of 31 miles, with an elevation change from 923 to 4,730 feet. Grandview Mt (Jennerstown), Pennsylvania, may be used as an alternate mountain road-load course, as the gradient meets the minimum requirements.

(3) The full throttle road-load cooling tests, maximum safe speed, and mountain road-load, should be conducted in two vehicle configurations as follows:

(a) First Configuration. The vehicle is prepared as if for full load cooling testing (thermostats blocked open, bypasses closed and the cooling fans locked on). This configuration is used when the critical component temperatures are to be extrapolated to the vehicles required ambient operating temperature.

(b) Second Configuration. The vehicle is in the standard operational configuration with all fans and thermostats being fully functional. It is of particular interest on systems that utilize thermostatically- or operator-controlled cooling fans to evaluate their performance and reliability of operation at elevated temperatures. Component temperature data are not generally extrapolated to 120°F but are presented as repeatable average maxima encountered during operations.

(4) Operate the vehicle at maximum safe speeds, not exceeding speed limits, for sufficient time prior to starting the mountain grade course such that critical component temperatures stabilize at normal operating temperature. Approximately 40 minutes to 1 hour of operation before proceeding up the mountain grade at full throttle should be sufficient at high ambient temperatures.

(5) After reaching normal operating temperature, proceed to ascend the mountain grade at full throttle, in the pre-determined gear range selected for the test, until the end of the course is reached or temperatures exceed critical limits.

4.5 Auxiliary Engine Tests.

a. Determine the cooling characteristics of auxiliary engines.

b. Apply a controlled load to the auxiliary engine and subject it to the following test configurations with the main engine operating:

(1) Operate the vehicle over a paved highway at maximum engine torque output until critical component temperatures stabilize or exceed critical limits. Record data in Paragraph 5.5.a(5) through 5.5.a(13). Not applicable for vehicles whose auxiliary engines may only be used when the vehicle is stationary.

(2) Operate the auxiliary engine at 75% of its rated load until its critical component temperature stabilizes and record data as prescribed in Paragraph 5.5b.

(3) Operate the auxiliary engine at 90% of its rated load until its critical component temperature stabilizes and record data as prescribed in Paragraph 5.5b.

(4) Operate the auxiliary engine at 100% of its rated load until its critical component temperature stabilizes and record data as prescribed in Paragraph 5.5b.

4.6 Temperature Rise from Steering (Tracked Vehicles).

Determine the effect of transmission-controlled steering systems (tracked vehicles), when applicable, as follows:

a. Prepare the vehicle so that it is instrumented and loaded as stated in Paragraph 3.3.

b. Operate the test vehicle over a test course, requiring frequent steering maneuvers, at maximum safe operating speed.

c. Operate the vehicle for a sufficient period of time to determine whether critical component temperatures exceed limitations during operation.

5. DATA REQUIRED.

5.1 Resistance-to-Motion.

Reference requirements defined in TOP 2-2-605[5], "Wheeled Vehicle Towing Resistance."

5.2 Drawbar Pull.

Reference requirements defined in TOP 2-2-604[6], "Drawbar Pull."

5.3 Full Load Cooling Tests (Wide Open Throttle).

5.3.1 General Method.

a. Drawbar pull, engine speed, road speed, sprocket speeds, and fan speeds.

b. Component temperatures.

c. Component pressures or pressure drops.

d. Fuel temperatures to and from engine.

e. Fuel pressures before and after fuel filters.

f. Inlet and outlet fluid temperatures of components and coolers.

g. Exhaust gas temperatures.

h. Air temperatures before and after fluid-to-air coolers.

i. Transmission gear selection (range and converter or lockup).

j. Other fluid/air and surface temperatures appropriate for evaluation, for human factors, or material considerations (such as heat damage to exhaust hangers or other components).

k. Meteorological data (ambient temperature, wind speed, wind direction, solar radiation, barometric pressure, relative humidity, and altitude).

l. Wheel or track slip.

m. Torque converter speed ratio.

n. Steering pump and PTO power, as applicable.

o. Parasitic electrical or hydraulic load, as applicable.

p. Other special measurements as appropriate.

5.3.2 Vehicles with Clutch Operated/Manual-Shifted Mechanical Transmissions.

a. Data obtained after temperature stabilization must be derived from equal operational time in both directions of travel to minimize wind effects and the effects of road grade on drawbar data. Ten minutes of stabilized critical component temperatures (a minimum of 11 readings, 1 minute apart) in each direction of travel is considered adequate. If critical component temperatures do not stabilize, the maximum values obtained are presented.

b. Record the applicable data requirements of Paragraph 5.3.1.

5.3.3 Vehicles with Automatic-Shift Transmissions.

a. Data obtained after temperature stabilization must be derived from equal operational time in both directions of travel to minimize wind effects and the effects of road grade on drawbar data. Ten minutes of stabilized critical component temperatures (a minimum of 11 readings, 1 minute apart) in each direction of travel is considered adequate. If critical component temperatures do not stabilize, the maximum values obtained are presented.

b. Record the applicable data requirements of Paragraph 5.3.1.

5.4 Road-load Cooling Tests (Without a Field Dynamometer)

a. Engine speed.

b. Road speed.

c. Wheel or sprocket speed.

d. Engine cooling fan speed.

e. Critical component temperatures.

f. Inlet and outlet fluid temperatures from components.

g. Inlet and outlet fluid temperatures from coolers/radiators.

h. Area meteorological data (ambient temperature, wind speed and direction, and relative humidity).

i. Ambient mast temperature.

j. Elevation of vehicle.

k. Throttle position.

l. Transmission gear range selector position.

m. Gear range in use.

5.5 Auxiliary Engine Tests.

a. Record the following:

(1) Location of the auxiliary engine.

(2) Auxiliary engine model, serial number, and manufacturer.

(3) Auxiliary engine maximum allowable temperature.

(4) Auxiliary engine rated load.

(5) Vehicle transmission position.

(6) Meteorological data.

(7) Vehicle direction.

(8) Air induction through the vehicle engine compartment.

(9) Air induction through the turret, if applicable.

(10) Main engine oil pressure.

(11) Main engine speed.

(12) Vehicle speed.

(13) Air temperature around the auxiliary engine prior to and while operating the auxiliary engine.

b. Record the following:

(1) Auxiliary engine critical component stabilized temperature, oil temperature, and pressure. If engine is liquid-cooled, also record coolant temperature.

(2) Vehicle critical component temperatures.

5.6 Temperature Rise from Steering (Tracked Vehicles).

a. Component temperatures, pressures, and air flow rates pertinent to evaluation of differential steering effects.

b. Average engine speed and distribution of engine speed (histogram).

c. Average vehicle speed and distribution of road speed (histogram).

d. Meteorological data.

e. Number of shifts – converter speed ratio distribution.

6. PRESENTATION OF DATA.

6.1 Extrapolation Method.

In order to evaluate vehicular performance at an ambient temperature specified by vehicle performance specifications (commonly 49°C (120°F)), an extrapolation technique is used to predict vehicle temperatures at the specified ambient temperature. In this circumstance, it is common practice to extrapolate the demonstrated vehicle performance to estimate performance at the specification temperature using a direct 1:1 extrapolation, where 1 degree is added to the measured component temperature for each 1 degree the ambient is below the specification temperature. Cooling system tests should be scheduled such that the ambient temperature is as high as possible to minimize any extrapolation errors.

6.2 Data Reduction Methods and Presentation.

a. Data processing and results are primarily dictated by the specific requirements of the item under test. In general, the following data must be collected, reduced, and presented in tabular or graphical format as necessary (sample data presentations are shown as Tables 6.2-1 through 6.2-3 and Figure 6.2-1):

(1) Measured and extrapolated averages of key component temperatures (if stabilized).

(2) Measured and extrapolated key component temperature maxima and/or rate of rise (if not stabilized).

(3) Average road speed, engine speed, and drawbar load during the stabilized period or at the specified test conditions.

(4) Other measures as dictated by test requirements.

b. The apparent effects of auxiliary engine, differential steering, etc., upon the vehicle engine and transmission cooling systems shall be summarized in tabular format.

TABLE 6.2-1. Test Conditions Summary

Configuration No.		1		
Date		dd mm yy		
Direction of Travel		North	South	Overall Average
Time of Day		hh:mm to hh:mm	hh:mm to hh:mm	
Gross Vehicle Weight	N (lb)	154,576 (34,750)	154,576 (34,750)	154,576 (34,750)
Average Drawbar Load	N (lb)	90,659 (20,381)	93,266 (20,967)	91,963 (20,674)
Resistance-to-Motion Load	N (lb)	2,917 (656)	2,917 (656)	2,917 (656)
TE/GVW		0.605	0.622	0.614
Avg Ambient Temp	°C (°F)	22 (71.6)	22 (71.6)	22 (71.6)

TABLE 6.2-2. Temperature Data

Parameter	Critical Temp Limit °C (°F)	North Avg °C (°F)	South Avg °C (°F)	Overall Avg °C (°F)	Overall Extrap Temps °C (°F)
Avg Ambient Temp	39 (120)	22 (72)	22 (72)	22 (72)	NA
Ambient Mast on Veh	NA	22 (72)	22 (72)	22 (72)	49 (120)
Coolant to Radiator	110 (230)	84 (183)	86 (187)	85 (185)	112 (234)
Coolant from Radiator	NA	79 (174)	82 (180)	80 (176)	107 (225)
Coolant from Transmission Cooler	NA	78 (172)	80 (176)	79 (174)	106 (223)
Engine Oil Sump	135 (275)	107 (225)	109 (228)	108 (226)	136 (277)
Engine Oil Gallery	NA	96 (205)	98 (208)	97 (207)	125 (257)
Drop Box Sump	149 (300)	100 (212)	99 (210)	100 (212)	127 (261)
Transmission Sump	149 (300)	85 (185)	86 (187)	85 (185)	113 (235)
Key: NA – Not Applicable					

TABLE 6.2-3. Linear and Rotational Speed Data

Parameter	North Avg	South Avg	Overall Avg
Eng Speed, rpm	2,030	2,040	2,035
Road Speed, km/hr (mph)	5.0 (3.1)	5.1 (3.2)	5.15 (3.15)
Fan Speed, rpm	2,020	2,030	2,025
Sprocket, rpm	24.1	24.4	24.25

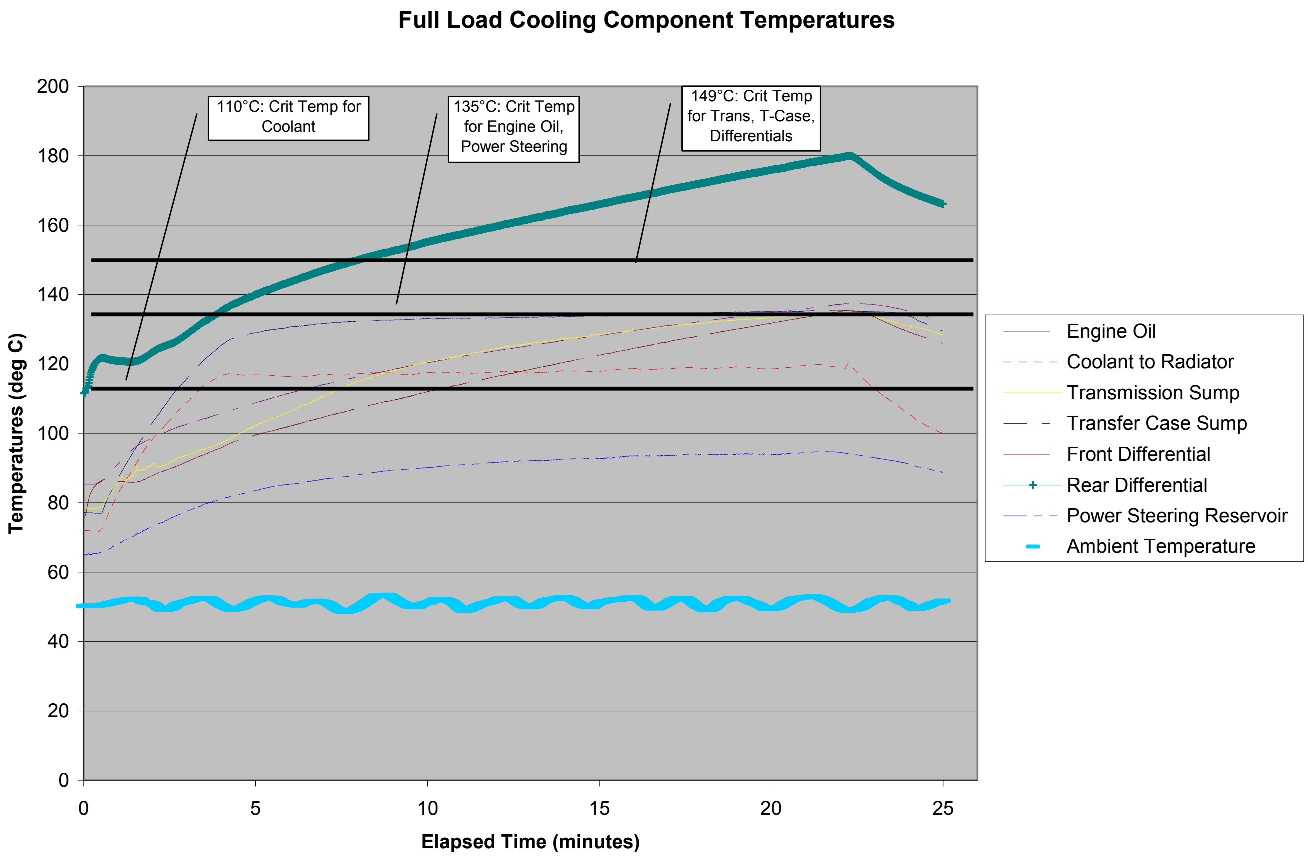

FIGURE 6.2-1. Sample plot of cooling data

APPENDIX A. RECOMMENDED OPERATIONAL TEMPERATURE LIMITS FOR LUBRICATING OILS AND HYDRAULIC FLUIDS (from Memorandum on Temperature Limits for Lubricating Oils and Hydraulic Fluids, dated 1 February 1989)

Fluid or Lubricant		Maximum Allowable Temperatures	
		Sustained Operation	Short Period Operations (15 min)
Engine Lubricants	MIL-L-2105D MIL-L-21260D MIL-L-46152E MIL-L-46167B (OEA)	120ºC (250ºF) for engine use 150ºC (300ºF) for automatic transmission or gearbox use	135ºC (275ºF) for engine use 150ºC (300ºF) limit should not be exceeded for automatic transmission or gearbox use
Brake Fluids	VV-B-680C	130ºC (265ºF)	150ºC (300ºF)
	MIL-B-46176A	130°C (265°F)	205°C (400°F)
Hydraulic Fluids	MIL-H-5606F	70ºC (160ºF) open system 275ºF (135ºC) closed system	260ºC (500ºF) if system is sealed and inert gas pressurized
	MIL-H-6083E	70ºC (160ºF) open system 120ºC (250ºF) closed system	135ºC (275ºF)
	MIL-H-46170B	120ºC (250ºF)	135ºC (275ºF)
Gear Oil	MIL-L-2105D	120ºC (250ºF)	150ºC (300ºF)
Transmission Fluid	Dexron II and Dexron III	150ºC (300ºF)	150ºC (300ºF)

APPENDIX B. GLOSSARY

Drawbar Pull	–	Reserve motive force available for acceleration, ascent of grades, towing of trailers or large payloads, or overcoming obstacles.
Mobile Dynamometer	–	Vehicle used to provide a calibrated retarding force to a vehicle under test.
Full Load Cooling	–	Cooling system test performed to evaluate engine and drive train cooling characteristics during maximum-effort operations (e.g., maximum power and high ambient temperatures).
Resistance to Motion	–	A speed-dependent force representing the parasitic power losses of the test vehicle's drive train, tire rolling resistance, grade resistance, and aerodynamic drag.
Retardation	–	Force applied to resist motion.
Road-load Cooling	–	Cooling system test performed to evaluate engine cooling characteristics during typical operations.
Tractive Effort	–	Total force available at the road surface to move the vehicle.
Wide-Open Throttle	–	Maximum throttle.

APPENDIX C. ABBREVIATIONS

AMCP	-	U.S. Army Materiel Command Pamphlet
AR	-	Army Regulation
ASTM	-	American Society for Testing and Materials
CTIS	-	Central Tire Inflation System
DBP	-	Drawbar pull
GPS	-	Global Positioning System
GCW	-	Gross combat weight
GVW	-	Gross vehicle weight
HFE	-	Human Factors Engineering
IAW	-	In accordance with
ITOP	-	International Test Operations Procedure
POL	-	Petroleum, Oils, and Lubricants
PTO	-	Power Take-off
rpm	-	revolutions per minute
SAE	-	Society of Automotive Engineers
TE	-	Tractive Effort
TE/GVW	-	Tractive Effort to Gross Vehicle Weight Ratio
TM	-	Technical Manual
TOP	-	Test Operations Procedure

APPENDIX D. REFERENCES

1. Form and Style for ASTM Standards, ASTM International, dated March 2005.

2. TOP 2-2-505, Inspection and Preliminary Operation of Vehicles, dated 4 February 1987.

3. SAE J1393, On-Highway Truck Cooling Test Code, SAE International, dated February 1999.

4. AMCP 706-361, Engineering Design Handbook, Military Vehicle Power Plant Cooling.

5. TOP 2-2-605, Wheeled Vehicle Towing Resistance, dated 29 July 1993.

6. TOP 2-2-604, Drawbar Pull, dated 18 July 1980.

For information only (related publications).

a. AR 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions, dated 16 September 1979.

b. FR/GE/UK/US International Test Operations Procedure (ITOP) 2-2-607 (1), Tracked Vehicle Full Load Cooling.

c. Test Procedure 2-2-702, Effects of Altitude on Automotive Engines.

d. FR/GE/UK/US ITOP 2-2-702(1), Tracked Vehicle Altitude Effects.

e. Test Operating Procedures (TOP) 1-1-058, Temperature Measuring Devices.

f. TOP 2-1-005, Automotive Field Test Equipment and Instrumentation.

g. FR/GE/UK/US ITOP 2-2-605, Tracked Vehicle Towing Resistance.

h. TOP 2-1-001, Testing Wheeled, Tracked, and Special Purpose Vehicles.

i. Material Test Procedure 2-1-002, Automotive Laboratory Instrumentation.

j. TOP 2-2-816, High and Low Temperature Test of Vehicle.

k. Petroleum, Oils, and Lubricants (POL) Products Guide, Fuels and Lubricants, TARDEC, dated March 2006.

l. Memorandum on Temperature Limits for Lubricating Oils and Hydraulic Fluids, dated 1 February 1989.

m. YPG Report No. 221, Methodology Investigation, Prediction-Comparison-Verification Studies for Automotive Cooling Evaluation.

n. Ayaji-Majebi, Abayomi. Full Load Cooling Test (FLCT) Correlation and Extrapolation Factor Studies of Top Tank Temperatures for Military Vehicles Using Historical FLCT Data, dated 4 March 2005.

o. Second Letter Report on Special Study to Investigate Validity of Automotive Cooling Test Data Extrapolation Techniques.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division, CSTE-DTC-TM-B, U.S. Army Developmental Test Command, 314 Longs Corner Road, Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Combat and Automotive Systems Division, CSTE-DTC-YP-YT-GC-EV, U.S. Army Yuma Proving Ground, Yuma Test Center, 301 C. Street, Yuma, AZ 85365-9498. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd, STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.